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Reaction of N-Haloamide. XX.[1] Bromo-formyloxylation of α,β-Unsaturated Esters with N,N-Dibromobenzenesulfonamide and Formic Acid[2]

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α,β-Unsaturated esters were made to react with N,N-dibromobenzenesulfonamide and formic acid in chloroform to give bromo-formyloxyesters. Methyl acrylate (**1a**), ethyl crotonate (**2a**), ethyl *trans*-cinnamate (**3a**), methyl tiglate (**4a**), methyl methacrylate (**5a**), and methyl phenylacrylate (**6a**) gave methyl 2-bromo-3-formyloxypropionate (**1b**), ethyl *erythro*-2-bromo-3-formyloxybutyrate (**2b**), ethyl *erythro*-2-bromo-3-formyloxy-3-phenylpropionate (**3b**), methyl *erythro*-2-bromo-3-formyloxy-2-methylbutyrate (**4b**), a mixture of methyl 3-bromo-2-formyloxy-2-methylpropionate (**5b**) and methyl 2-bromo-3-formyloxy-2-methylpropionate (**5c**), and methyl 3-bromo-2-formyloxy-2-phenylpropionate (**6b**) respectively in good yields.

We have reported in the previous paper[4] that the reaction of olefines with N,N-dibromobenzenesulfonamide (DBBS) and 99% formic acid gave bromo-formyloxylates in good yield. This paper deals with a simple method for bromo-formyloxylation of six kinds of α,β-unsaturated esters in satisfactory yields using DBBS and formic acid. A general procedure for this purpose was established; namely α,β-unsaturated ester, 99% formic acid, and DBBS in the molar ratio of 2: 6: 1 were made to react in chloroform at room temperature for several hours. From methyl acrylate (**1a**), methyl 2-bromo-3-formyloxypropionate (**1b**) was obtained as a colorless oil, bp 77—79° (5 mmHg), which was hydrolyzed with 1% hydrochloric acid to give corresponding bromohydrin (**1c**). The structure of **1c** was found to be 2-bromo-3-hydroxypropionate by showing characteristic two fragments, *m/e* 182 and 184 (M^+, 1: 1), and 151 and 153 (M^+-CH_2OH, 1: 1) and lacking *m/e* 93 and 95 ($M^+-CH(OH)-COOCH_3$, 1: 1) in the mass spectrum.[5] The bromohydroxylation of **1a** with DBBS in acetic acid–water also gave **1b**.

General procedure starting from ethyl crotonate (**2a**) gave ethyl *erythro*-2-bromo-3-formyloxybutyrate (**2b**), colorless oil, bp 95—98° (7 mmHg), in 80% yield. The hydrolysis of **2b** with hot 3% hydrochloric acid for 1 hr followed by extraction of acidic part of the hydrolyzate yielded colorless crystals, mp 86—87° (**2c**), which were identified with the authentic sample of *erythro*-2-bromo-3-hydroxybutyric acid, mp 85—88°.[6] Treatment of ethyl *trans*-cinnamate (**3a**) according to the general procedure gave oily bromo-formyloxy compound (**3b**), bp 155—156° (6 mmHg), in 90.4% yield. Heating of **3b** with 5% hydrochloric acid for 3 hr followed by the speration of the hydrolyzate to acidic and neutral fractions gave *erythro*-2-bromo-3-hydroxy-3-phenylpropionic acid (**3c**), mp 124—126°, from the former fraction and bromohydroxy ester (**3d**), mp 81.5—82.5°, from the latter one. The compound (**3c**), was identified with authentic sample synthesized from cinnamic acid by Dalton's method.[7]

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[1] Part XIX: Y. Kamiya and S. Takemura, *Chem. Pharm. Bull.* (Tokyo), **20**, 201 (1974).

[2] The report has been presented in brief at the 23rd Meeting of Kinki Branch of the Pharmaceutical Society of Japan, Kyoto, November, 1973.

[3] Location: *Kowakae, Higashi-osaka, Osaka.*

[4] H. Niizato, Y. Ueno, and S. Takemura, *Chem. Pharm. Bull.* (Tokyo), 20, 2707 (1972).

[5] Similar fragments have been observed in the mass spectrum of the bromohydroxylated product of cinnamic ester, P.B.D. de la Mare and M.A. Wilson, *J. Chem. Soc., Parkin II*, **1973**, 653.

[6] H.E. Carter and C.L. Zirkle, *J. Biol. Chem.*, **78**, 709 (1949).

[7] D.R. Dalton, R.C. Smith, Jr., and D.G. Jones, *Tetrahedron*, **26**, 575 (1970).

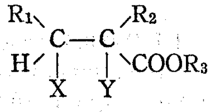
The reaction started from methyl tiglate (**4a**) afforded an oily bromo-formyloxy compound (**4b**), bp 80—81° (7 mmHg), in 77% yield. The hydrolysis of **4b** with 3% hydrochloric acid followed by extraction of neutral fraction gave a bromohydrin ester (**4c**). This compound was shown to be an ester having bromine in C2 exhibiting characteristic peaks, *m/e* 210 and 212 (M^+, 1: 1), 165 and 167 (M^+-CH_3CHOH, 1:1), and 134 and 136 (M^+-CH_3CHOH-OCH_3, 1: 1). Epoxidation of **4c** with sodium ethoxide gave an oil (**4d**), bp 43—44° (6 mmHg), which was identified with *trans*-2,5-epoxy-2-methylbutyrate, bp 50—55° (14 mmHg) obtained by epoxidation of **4a** with *m*-chloroperbenzoic acid. On these basis, **4d** has a *trans* and **4b** has an *erythro* configurations.

From methyl methacrylate (**5a**), an oily product, bp 74—76° (5 mmHg), was obtained in 85% yield. The elemental analysis of this product agreed with the molecular formula, $C_6H_9O_4Br$, which showed that the product was bromo-formyloxy compound. The nuclear magnetic resonance (NMR) spectrum of this product exhibits two kinds of methyl signals at δ 1.72 and 1.94. The separation of the components by gas chromatography was unsuccessful but the material was supposed to be a mixture of methyl 2-bromo-3-formyloxy-2-methylpropionate (**5b**) and its isomer (**5c**). The material was hydrolyzed with hot 1% hydrochloric acid and from the neutral hydrolyzate, a colorless oil, bp 69.5—70.5° (5 mmHg), $C_5H_9O_3Br$, was obtained. Two peaks at t_R 8.9 min., and t_R=13.2 min. were observed in gas chromatogram of the hydrolyzate. The NMR spectrum of this also exhibited two methyl signals at 1.56 and 1.94 ppm. The ratio of the compounds was calculated as about 50: 50 from the peak areas. The components were supposed to be methyl 2-bromo-3-hydroxy-2-methylpropionate (**5d**) and its isomer (**5e**).

Martynov[8] has reported that bromo-hydroxylation of **5a** with N-bromoacetamide gave **5d**. However, our trace resulted in a mixture of **5d** and **5e**.

The said mixture of **5b** and **5c** was hydrolyzed by heating with 3.5% hydrochloric acid. From acidic fraction of the hydrolyzate, 3-bromo-2-hydroxy-2-methylpropionic acid (**5f**) was obtained which was identified with the authentic sample,[9] mp 102—103°. Since the NMR spectrum of the neutral fraction of the hydrolyzate suggested that it contained **5d** contaminated with **5e** in 20%, the mixture was chromatographed on silica gel column to

TABLE I. Bromo-formyloxy Compounds from α,β-Unsaturated Esters, DBBS, and Formic Acid



No.	Unsaturated ester	No.	Product					bp °C(mm/Hg) or (mp °C)	Yield %
			R_1	R_2	R_3	X	Y		
1a	CH_2=CH-$COOCH_3$	**1b**	H	H	CH_3	OCHO	Br	77— 79(5)	72.5
2a	CH_3-CH=CH-$COOC_2H_5$ (*trans*)	**2b**	CH_3	H	C_2H_5	OCHO	Br	95— 98(7)	80
3a	C_6H_5-CH=CH-$COOC_2H_5$ (*trans*)	**3b**	C_6H_5	H	C_2H_5	OCHO	Br	155—156(5)	90
4a	CH_3-CH=C(CH_3)$COOCH_3$ (*trans*)	**4b**	CH_3	CH_3	CH_3	OCHO	Br	80— 81(7)	77
5a	CH_2=C(CH_3)$COOCH_3$	**5b** **5c**	H H	CH_3 CH_3	CH_3 CH_3	OCHO Br	Br OCHO	74— 76(5)	85
6a	CH_2=C(C_6H_5)$COOCH_3$	**6b**	H	C_6H_5	CH_3	Br	OCHO	136—138(4) (mp 45—46)	69.5

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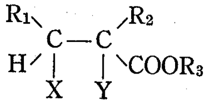
8) V.F. Martynov and I-Ming Chou, *Zhur, Obshcker Khim.*, **30**, 3174 (1960) [*C.A.* **55**, 21042*c* (1961)].
9) C. Kolbe, *J. Prakt. Chem.*, [2], **25**, 374, 376 (1882).

Table II. Bromohydrin Compounds and Oxide from Formyloxy Compounds



Compound No.	R_1	R_2	R_3	X	Y
1c	H	H	CH_3	OH	Br
2c	CH_3	H	H	OH	Br
3c	C_6H_5	H	H	OH	Br
3d	C_6H_5	H	C_2H_5	OH	Br
4c	CH_3	CH_3	CH_3	OH	Br
4d	CH_3	CH_3	CH_3	-O-	
5d	H	CH_3	CH_3	OH	Br
5e	H	CH_3	CH_3	Br	OH
5f	H	CH_3	H	Br	OH
6c	H	C_6H_5	CH_3	Br	OH

isolate **5d**, bp 69—71° (5 mmHg). The mass spectrum, *m/e* 196 and 198 (M^+, 1: 1), and 165 and 167 (M^+, $-CH_2OH$, 1: 1) supports the structure of **5d**. From methyl phenylacrylate (**6a**), methyl 3-bromo-2-formyloxy-2-phenylpropionate (**6b**), mp 45—46°, bp 136—138° (4 mmHg) was obtained in 69.5% yield. Hydrolysis of **6b** with 3% hydrochloric acid gave bromo-hydroxyester (**6c**) which was proved to be methyl 3-bromo-2-hydroxy-2-phenylpropionate by showing peaks at *m/e* 258 and 260 (M^+, 1: 1), and 93 and 95 (M^+, $-C(OH)(C_6H_5)COOCH_3$, 1: 1) in mass spectrum.

In conclusion, bromo-formyloxylation of **1a**—**4a** gave exclusively 2-bromo adducts, **1b**—**4b**, while the reaction of **5a** gave a mixture of 2-bromo and 3-bromo isomers and that of **6a** afforded only 3-bromo analogue, **6b**, by the effect of groups in C2 position. The formation of *erythro* adducts from *trans* ester, **2a**, **3a**, and **4a** shows that the reaction proceeds with *trans* addition. An experiment using bromine instead of DBBS gave no bromo-formyloxy product but only dibromo adduct.

Experimental

Mass spectra were recorded with a Shimazu LKB-9000 mass spectrometer with an accelerating potential of 3.5 kV, an ionizing potential of 70 eV and a source temperature of 25—150°. Gas-liquid chromatography (GLC) was run on Hitachi Model K-23 gas chromatograph at 152° using a stainless steel column (2 m × 3 mm i.d.) of 15%, ethylene glycol succinate (EGS) on Neopak (60—80 mesh) with a He flow of 10 ml/min.

General Procedure——N,N-Dibromobenzenesulfonamide (DBBS) (0.1 mole) was added to a solution of α,β-unsaturated ester (0.2 mole) and 99% formic acid (0.6 mole) in $CHCl_3$ (35 ml) with stirring in a period of about 40 min keeping the temperature at 10—15°. The stirring was continued for additional a few hr at room temperature. The separated crystals of benzenesulfonamide were filtered off by suction, and washed with $CHCl_3$. The filtrate was washed with H_2O, and dried over anhyd. Na_2SO_4. After removal of $CHCl_3$ under reduced pressure, the resulting residue was distilled.

Methyl 2-Bromo-3-formyloxypropionate (1b)——General procedure starting from methyl acrylate (**1a**) (17.2 g, 0.2 mole), 99% formic acid and DBBS (31.5 g, 0.1 mole), and additional stirring of the mixture for 6 hr resulted an oil. The oil was distilled to give a colorless liquid, **1b**, bp 77—79° (5 mmHg). Yield. 31.7 g (72.5%). *Anal.* Calcd. for $C_5H_7O_4Br$: C, 28.46; H, 3.34. Found: C, 28.00; H, 3.30. n_D^{18} 1.4692. IR $\nu_{max}^{liq.}$ cm^{-1}: 1740 (C=O). NMR ($CDCl_3$) δ: 3.84 (3H, s, $-OC\underline{H}_3$), 4.3—4.7 (3H, m, $-C\underline{H}-C\underline{H}_2Br$), 8.08 (1H, s, $-OC\underline{H}O$).

Methyl 2-Bromo-3-hydroxypropionate (1c)——a) Hydrolysis of **1b**: **1b** (5 g) was refluxed for 30 min with 30 ml of a mixture of H_2O–EtOH–conc. HCl (79: 20: 1). The solvent was distilled off from the reaction mixture, and the residue was neutralized with aq. $NaHCO_3$. The solution was then extracted with ether (15 ml × 4). The combined ether layer was washed with H_2O, dried over anhyd. Na_2SO_4, and the solvent was distilled off. The residue was distilled to give a colorless liquid **2b**, bp 86—87° (7 mmHg). Yield 1.5 g (34.6%). *Anal.* Calcd. for $C_4H_7O_3Br$: C, 26.25; H, 3.86. Found: C, 26.35; H, 4.10. n_D^{18} 1.4820. IR $\nu_{max}^{liq.}$

cm^{-1}: 3500 (–OH). NMR ($CDCl_3$) δ: 3.95 (1H, d, J=2 Hz, $\substack{H\\H}\!>\!\underset{\substack{|\\OH}}{C}-$ or $\substack{H\\\underline{H}}\!>\!\underset{\substack{|\\OH}}{C}-$), 4.05 (1H, d, J=2 Hz, $\substack{\underline{H}\\H}\!>\!\underset{\substack{|\\OH}}{C}-$ or $\substack{H\\\underline{H}}\!>\!\underset{\substack{|\\OH}}{C}-$), 4.39 (1H, t, J=5 Hz, –C$\underline{H}$Br), 3.0 (1H, s, –$CH_2O\underline{H}$). Mass Spectrum *m/e*: 182/184 (M^+, 1 : 1), 151/153 (M^+–CH_2OH, 1 : 1), 120/122 (M^+–CH_2OH–OCH_3, 1 : 1). The infrared (IR) spectrum of this compound was coincident with that of the product of procedure b.

b) From **1a**: Glacial acetic acid (7 g) was added to the ice cooled solution of DBBS (18.3 g) dissolved in a mixture of H_2O (20 ml), and acetone (20 ml). **1a** (10 g) was added into the solution in a period of 10 min under stirring and cooling at 5—10°. The mixture was stirred for another 15 hr at room temperature.

Acetone was removed from the reaction mixture by distillation and the separated crystals of benzenesulfonamide were filtered. The mother liquor was extracted with ether (15 ml × 3). After drying over anhyd. Na_2SO_4, the ether layer was concentrated to dryness. The residual oil was distilled at 70—73° (4 mmHg). Yield 11.1 g (52.2%). The product was identified with **1c** prepared by method a.

Ethyl *erythro*-2-Bromo-3-formyloxybutyrate (2b)——The crude product obtained by the reaction of DBBS (9.4 g, 0.03 mole), and 99% formic acid with ethyl crotonate (**2a**) (6.85 g, 0.06 mole) was distilled *in vacuo* to give an oil, bp 95—98° (7 mmHg). Stirring for 1.5 hr was required to complete the reaction. Yield 11.4 g (80%). *Anal.* Calcd. for $C_7H_{11}O_4Br$: C, 35.17; H, 4.64. Found: C, 35.49; H, 4.67. n_D^{18} 1.4560. NMR ($CDCl_3$) δ: 1.3 (3H, t, J=7 Hz, –$CH_2C\underline{H_3}$), 1.5 (3H, d, J=6 Hz, $-\underset{\substack{|\\CH_3}}{C}HOCHO$), 4.1—4.4 (3H, m, –C$\underline{H}$Br, –$OC\underline{H_2}CH_3$), 5.4 (1H, m, J=7 Hz, –C$\underline{H}$OCHO), 8.02 (1H, d, J=2 Hz, –OC$\underline{H}$O).

***erythro*-2-Bromo-3-hydroxybutyric Acid (2c)**——**2b** (3.5 g) was refluxed for 1 hr with 30 ml of a mixture of H_2O–EtOH–conc. HCl (79 : 20 : 1), then EtOH was removed from the reaction mixture under reduced pressure. The residue was made alkaline with aq. $NaHCO_3$. The alkaline solution was extracted with ether (15 ml × 3) to remove side product. The aqueous layer was acidified with dil. HCl, and extracted with ether (15 ml × 4). Drying over Na_2SO_4 followed by evaporation of the solvent from ether extract left an oil which soon solidified. The solid was recrystallized from $CHCl_3$ giving colorless needles (**2c**), mp 86—87°. Yield 0.8 g (30%). The comparison of IR spectra and mixed melting point determination of this product with **2c** prepared by Cater's method$^{6)}$ left no doubt on the identity of them.

Ethyl *erythro*-2-Bromo-3-formyloxy-3-phenylpropionate (3b)——This compound was prepared by general procedure starting from ethyl *trans*-cinnamate (**3a**) (31.7 g, 0.18 mole), 99% formic acid and DBBS (28.2 g, 0.09 mole). The reaction was completed after 2 hr. The resulting oil was distilled to yield a pale yellow liquid (**3b**), bp 155—156° (6 mmHg). Yield 49 g (90.4%). *Anal.* Calcd. for $C_{12}H_{13}O_4Br$: C, 47.86; H, 4.35. Found: C, 48.04; H, 4.55. n_D^{18} 1.5277. NMR ($CDCl_3$) δ: 1.3 (3H, t, J=7.5 Hz, –$OCH_2C\underline{H_3}$), 4.25 (2H, q, J=7 Hz, –$OC\underline{H_2}CH_3$), 4.5 (1H, d, J=9 Hz, –C$\underline{H}$OCHO or –C$\underline{H}$Br), 6.22 (1H, d, J=9 Hz, –C$\underline{H}$OCHO or –C$\underline{H}$Br), 7.34 (5H, s, arom.).

Hydrolysis of 3b——a) Ethyl *erythro*-2-Bromo-3-hydroxy-3-phenylpropionate (**3d**): **3b** (8 g) was refluxed in 72 ml of a mixture of H_2O–EtOH–conc. HCl (65 : 30 : 5) for 3 hr. The solvent was removed from the reaction mixture under reduced pressure, and the residue was made alkaline with $NaHCO_3$. The alkaline solution was exrtacted with ether (15 ml × 4). The ether layer was washed with H_2O, dried over anhyd. Na_2SO_4, and condensed. The resulting solid was recrystallized from $CHCl_3$ to give **3c**, mp 81—82°. Yield 1.4 g (17.5%). *Anal.* Calcd. for $C_{11}H_{13}O_3Br$: C, 48.35; H, 4.80. Found: C, 48.42; H, 4.76. IR $\nu_{max}^{liq.}$ cm^{-1}: 3450 (–OH). NMR ($CDCl_3$) δ: 1.28 (3H, t, J=7 Hz, –$OCH_2C\underline{H_3}$), 4.26 (2H, q, J=7 Hz, –$OC\underline{H_2}CH_3$), 4.36 (1H, d, J=8 Hz, –C$\underline{H}$OH or –C$\underline{H}$Br), 5.7 (1H, d, J=8 Hz, –C$\underline{H}$·OH or –C$\underline{H}$·Br), 7.36 (5H, s, arom.).

b) *erythro*-2-Bromo-3-hydroxy-3-phenylpropionic Acid (**3c**): The said aqueous layer in procedure a was acidified with dil. HCl, and extracted with ether (20 ml × 4). The ether layer was washed with H_2O, dried over anhyd. Na_2SO_4, and evaporated to dryness leaving a solid. The crude solid was recrystallized from $CHCl_3$ to give **3c**, mp 124—126°. Yield 0.9 g (13.8%). *Anal.* Calcd. for $C_9H_9O_3Br$: C, 44.09; H, 3.70. Found: C, 44.01; H, 3.67. IR ν_{max}^{Nujol} cm^{-1}: 3400 (–OH), 2600 (C=O). NMR ($CDCl_3$) δ: 4.42 (1H, d, J=8 Hz, –C$\underline{H}$Br or –C$\underline{H}$OH), 5.12 (1H, d, J=8 Hz, –C$\underline{H}$Br or –C$\underline{H}$OH), 5.8 (2H, s, –O$\underline{H}$, –COO$\underline{H}$), 7.4 (5H, s, arom.). It was identified with an authentic sample$^{7)}$ by comparison of IR spectra.

Methyl *erythro*-2-Bromo-3-formyloxy-2-methylbutyrate (4b)——The crude product obtained by the reaction of DBBS (31.5 g, 0.1 mole) and 99% formic acid with methyl tiglate (**4a**) (22.8 g, 0.2 mole) was distilled *in vacuo* to obtain a colorless oil, bp 80—81° (7 mmHg). The reaction required to complete for 7 hr. Yield 34 g (77%). *Anal.* Calcd. for $C_7H_{11}O_4Br$: C, 35.17; H, 4.64. Found: C, 35.21; H, 4.71. NMR ($CDCl_3$) δ: 1.51 (3H, d, J=6 Hz, –$CHC\underline{H_3}$), 1.90 (3H, s, –$CBrC\underline{H_3}$), 5.61 (1H, q, J=6 Hz, –C$\underline{H}CH_3$), 7.98 (1H, s, –OC$\underline{H}$O).

Methyl *erythro*-2-Bromo-3-hydroxy-2-methylbutyrate (4c)——**4b** (10 g) was refluxed for 2 hr with 80 ml of a mixture of H_2O–EtOH–conc. HCl (77 : 20 : 3). EtOH was removed from the reaction mixture by distillation. The residue was made alkaline with aq. $NaHCO_3$, and the solution was extracted with ether (20 ml × 4). Ether layer was washed with H_2O, dried over anhyd. Na_2SO_4, and then condensed. The residue was distilled to give a colorless liquid, **4c**, bp 92—93° (9 mmHg). Yield 4 g (45.3%). *Anal.* Calcd. for $C_6H_{11}O_3Br$:

C, 34.14; H, 5.25. Found: C, 34.33; H, 5.27. IR $\nu_{max}^{liq.}$ cm^{-1}: 3500 (-OH). NMR ($CDCl_3$) δ: 1.35 (3H, d, J=6 Hz, $-CHC\underline{H}_3$), 1.81 (3H, s, $-OC\underline{H}_3$), 3.2 (1H, broad, $-O\underline{H}$), 3.78 (3H, s, $-CHBrC\underline{H}_3$), 4.34 (1H, q, J=6 Hz, $-C\underline{H}CH_3$). Mass Spectrum m/e: 210/212 (M^+, 1: 1), 195/197 (M^+-CH_3, 1: 1), 165/167 ($M^+-CHOCCH_3$, 1: 1), 134/136 ($M^+-CHOH-OCH_3$, 1: 1).

Methyl *trans*-2,3-Epoxy-2-methylbutyrate (4d)——a) From **4c**: Na (0.5 g) in dry MeOH (10 ml) was added to **4c** (4 g) in benzene (10 ml) with stirring in a period of 30 min. The reaction mixture was filtered, and the filtrate was washed with 5% aq. AcOH, and extracted with ether (20 ml×4). The ether-extract was washed with H_2O, dried over anhyd. Na_2SO_4, and evaporated to dryness. The residue was distilled to give a colorless liquid, **4d**, bp 43—44° (6 mmHg). Yield 1.3 g (52%). *Anal.* Calcd. for $C_6H_{10}O_3$: C, 55.37; H, 7.75. Found: C, 55.16; H, 7.84. NMR ($CDCl_3$) δ: 1.38 (3H, d, J=5 Hz, $-CHC\underline{H}_3$), 1.54 (3H, s, $-\underset{\displaystyle C\underline{H}_3}{\underset{|}{C}}-COOCH_3$), 3.32 (1H, q, 5 Hz, $-C\underline{H}CH_3$), 3.75 (3H, s, $-COOC\underline{H}_3$).

This liquid was identified with a sample of **4d** prepared from methyl tiglate by the following method b showing coincident spectral data.

b) From **4a**: A solution of **4a** (1.14 g, 0.01 mole) in CH_2Cl_2 (10 ml) was mixed with 85% *m*-chloroperbenzoic acid (2.04 g, 0.01 mole) dissolved in CH_2Cl_2 (10 ml). The mixture was gently refluxed for 47 hr. After cooling, the solution was shaken with 10% aq. Na_2SO_3 to destroy excess peroxide. The organic layer was then shaken with 5% aq. $NaHCO_3$ to remove *m*-chloroperbenzoic acid. The CH_2Cl_2 solution was dried over anhyd. Na_2SO_4, and the solvent was evaporated. The residue was distilled *in vacuo* to obtain a colorless oil, bp 50—55° (14 mmHg). Yield 1.1 g (76%).

Methyl 2-Bromo-3-formyloxy-2-methylpropionate (5b) and Methyl 3-Bromo-2-formyloxy-2-methylpropionate (5c)——A mixture of **5b** and **5c** was prepared by general procedure from methyl methacrylate (**5a**) (20 g, 0.2 mole), 99% formic acid, and DBBS (31.5 g, 0.1 mole). The reaction was completed after 3 hr. The crude product was distilled to give a colorless liquid of a mixture of **5b** and **5c**, bp 74—76° (5 mmHg). Yield 38.2 g (85%). *Anal.* Calcd. for $C_6H_9O_4Br$: C, 32.02; H, 4.03. Found: C, 32.07; H, 4.24. NMR ($CDCl_3$) δ: 1.72 (3H, s, $-CBrC\underline{H}_3$ or $-\underset{\displaystyle OCHO}{\underset{|}{C}}-C\underline{H}_3$), 1.94 (3H, s, $-CBrC\underline{H}_3$ or $-\underset{\displaystyle OCHO}{\underset{|}{C}}-CH_3$).

Hydrolysis of a Mixture of 5b add 5c——a) Methyl 2-Bromo-3-hydroxy-2-methylpropionate (**5d**): 19.7 g of a mixture of **5b** and **5c** was refluxed in 150 ml of a mixture of H_2O–EtOH–conc. HCl (76.5: 20: 3.5) for 1 hr. Then, EtOH was removed from the reaction mixture by distillation. The residue was made alkaline with aq. $NaHCO_3$, and extracted with ether (40 ml×5). The ether layer was washed with H_2O, dried over anhyd. Na_2SO_4, and ether was evaporated. The resulting oil was distilled to yield a colorless liquid, bp 70—73° (5 mmHg). Yield 2 g. Gas chromatography (150°, 0.5 atm) of this oil showed two peaks with retention times of 8.9 and 13.2 min with area ratio of 2: 8. The $CHCl_3$ elute from the silica gel column (40 mm×320 mm) afforded 1.15 g of **5d** as colorless liquid, bp 69—71° (5 mmHg). Gas chromatography (152°, 0.5 atom) of this oil was shown to be pure one of the mixture (retention time, 13.2 min). *Anal.* Calcd. for $C_5H_9O_3Br$: C, 30.48; H, 4.60. Found: C, 30.24; H, 4.64. NMR ($CDCl_3$ δ: 1.94 (3H, s, $>CBrC\underline{H}_3$), 2.9 (1H, broad, $-O\underline{H}$), 3.7—4.2 (2H, two doublets, J=1, 1 Hz, $-C\underline{H}_2OH$), 3.82 (3H, s, $-COOC\underline{H}_3$). Mass Spectrum m/e: 196/198 (M^+, 1: 1), 165/167 (M^+-CH_2OH, 1: 1), 151/153 ($M^+-CH_2OH-CH_2$, 1: 1), 134/136 ($M^+-CH_2OH-OCH_3$, 1: 1).

b) 3-Bromo-2-hydroxy-2-methylpropionic Acid (**5f**): The water layer described above (procedure a) was acidified with dil. HCl. The solution was extracted with ether (50 ml×5). The ether layer was washed with H_2O, dried over anhyd. Na_2SO_4, and evaporated to dryness. The residue was soon solidified which was recrystallized from benzene to give colorless needles, mp 101—102°. Yield 1.4 g. *Anal.* Calcd. for $C_4H_7O_3Br$: C, 26.26; H, 3.86. Found: C, 26.51; H, 3.87. NMR ($CDCl_3$) δ: 1.62 (3H, s, $-\underset{\displaystyle OH}{\underset{|}{C}}-C\underline{H}_3$), 3.4—3.9 (2H, two doublets, J=1 Hz, $-C\underline{H}_2Br$), 6.28 (2H, broad, $-O\underline{H}$, $-COO\underline{H}$). The IR spectral comparison and mixed melting point determination of this compound with authentic sample[9] of **5f** left no doublt on the identity of them.

Methyl 2-Bromo-3-hydroxy-2-methylpropionate 5d and Methyl 3-Bromo-2-hydroxy-2-methylpropionate (5e)——a) Hydrolysis of a Mixture of **5b** and **5c**: A mixture (10 g) of **5b** and **5c** described above was refluxed for 30 min with 50 ml of a mixture of H_2O–EtOH–conc. HCl (79: 20: 1). EtOH was distilled off from the reaction mixture, and the residue was made alkaline with $NaHCO_3$. The solution was extracted with ether (15 ml×4). The ether layer was washed with H_2O, dried over anhyd. Na_2SO_4, and evaporated to leave an oil. The oil was distilled to give a colorless liquid of a mixture of **5d** and **5e**, bp 69.5—70.5° (5.5 mmHg). Yield 5.75 g (65%). *Anal.* Calcd. for $C_5H_9O_3Br$: C, 30.48; H, 4.60. Found: C, 30.74; H, 4.68. IR $\nu_{max}^{liq.}$ cm^{-1}: 3500 ($-O\underline{H}$), 1740 (C=O). NMR ($CDCl_3$) δ: 1.56 (3H, s, $-CBrC\underline{H}_3$ or $-\underset{\displaystyle OH}{\underset{|}{C}}-C\underline{H}_3$), 1.94 (3H, s, $-CBrCH_3$ or $-\underset{\displaystyle OH}{\underset{|}{C}}-C\underline{H}_3$), 2.91 (1H, broad, $-O\underline{H}$), 3.4—4.2 (4H, m, $-C\underline{H}_2Br$, $-C\underline{H}_2OH$), 3.82 (3H, s, $-COOC\underline{H}_3$), 3.84 (3H, s, $-COOC\underline{H}_3$). Gas chromatography (152°, 0.5 atm) of this oil showed two peaks with retention time of 8.9 and 13.2 min and area ratio of **5d** and **5e** was 1: 1.

b) From **5a**: Crude compound was prepared by Martynov's method[8] from methyl methacrylate (**5a**) (7.6 g, 0.076 mole). The resulting oil was distilled to give a colorless liquid of a mixture of **5d** and **5e**, bp 68—72° (5 mmHg). Yield 4.2 g (36.2%). The comparison of gas chromatographic, IR, and NMR data of this product with the product from above described method a showed the identity of them while both samples were mixture of **5d** and **5e**. The area ratio of **5d** and **5e** in gas chromatogram of the former sample was 2:1.

Methyl 3-Bromo-2-formyloxy-2-phenylpropionate 6b——The crude compound was prepared by general procedure starting from methyl phenylacrylate (**6a**) (5 g, 0.034 mole), 99% formic acid, and DBBS (5.4 g, 0.017 mole). The reaction was completed after 7 hr. The crude oil was distilled to give a colorless liquid **6b**, bp 136—138° (4 mmHg), which soon solidified. Recrystallization from *n*-hexane afforded colorless needles, mp 45—46°. Yield 6 g (69.5%), *Anal.* Calcd. for $C_{11}H_{11}O_4Br$: C, 46.01; H, 3.86. Found: C, 46.31; H, 3.79. NMR ($CDCl_3$) δ: 3.72 (3H, s, $-OC\underline{H}_3$), 4.88 (2H, q, $-C\underline{H}_2Br$), 7.4 (5H, m, arom.), 8.22 (1H, s, $-OC\underline{H}O$).

Methyl 3-Bromo-2-hydroxy-2-phenylpropionate 6c——**6b** (6 g) was refluxed for 1 hr with 30 ml of a mixture of H_2O–EtOH–conc. HCl (77:20:3). MeOH was removed from the reaction mixture, and the residue was made alkaline with $NaHCO_3$. The alkaline solution was extracted with ether 10 ml × 3. The ether layer was washed with H_2O, dried over anhyd. Na_2SO_4, and condensed to dryness. The residue was distilled to yield a colorless oil, bp 125° (5 mmHg). Yield 2.1 g (38%). *Anal.* Calcd. for $C_{10}H_{11}O_3Br$: C, 46.35; H, 4.28. Found: C, 46.39; H, 4.43. IR $\nu_{\max}^{\text{liq.}}$ cm^{-1}: 3450 (–OH). NMR ($CDCl_3$) δ: 3.64 (1H, d, J=1 Hz, $\genfrac{}{}{0pt}{}{\mathrm{H}}{\underline{\mathrm{H}}}{>}\underset{|}{\mathrm{C}}\mathrm{Br}$ or $\genfrac{}{}{0pt}{}{\underline{\mathrm{H}}}{\mathrm{H}}{>}\underset{|}{\mathrm{C}}\mathrm{Br}$), 3.7—4.2 (1H, broad, $-O\underline{H}$), 4.16 (1H, d, J=1.0 Hz, $\genfrac{}{}{0pt}{}{\underline{\mathrm{H}}}{\mathrm{H}}{>}\underset{|}{\mathrm{C}}\mathrm{Br}$ or $\genfrac{}{}{0pt}{}{\mathrm{H}}{\underline{\mathrm{H}}}{>}\underset{|}{\mathrm{C}}\mathrm{Br}$). Mass Spectrum *m/e*: 258/260 (M^+, 1:1), 93/95 (M^+–COH(Ph)$COOCH_3$).

Methyl 1,2-Dibromopropionate——Br_2 (8 g, 0.05 mole) was added to a solution of methyl acrylate (**1a**) (8.6 g, 0.1 mole) and 99% formic acid (11.4 ml, 0.3 mole) in $CHCl_3$ (20 ml) with stirring in a period of about 20 min keeping the temperature at 10—15°. The stirring was continued for 1 hr at room temperature. The $CHCl_3$ solution was washed with H_2O, and dried over anhyd. Na_2SO_4. After removal of $CHCl_3$ under reduced pressure, the resulting oil was distilled to give a colorless oil, bp 53—56° (4 mmHg). Yield **10** g. It was identified with an authentic sample[10] by comparison of IR spectra.

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[10] C.S. Marvel, J. Dec, H.G. Cooke, Jr., and J.C. Cowan, *J. Am. Chem. Soc.*, **62**, 3496 (1940).